Enhancing the Operation of Highly Varying Industrial Loads to Increase Electric Reliability, Quality, and Economics

Dr. Robert Kramer
Vice President & Chief Scientist
NiSource Energy Technologies

Department of Energy

Purdue University

Colorado School of Mines

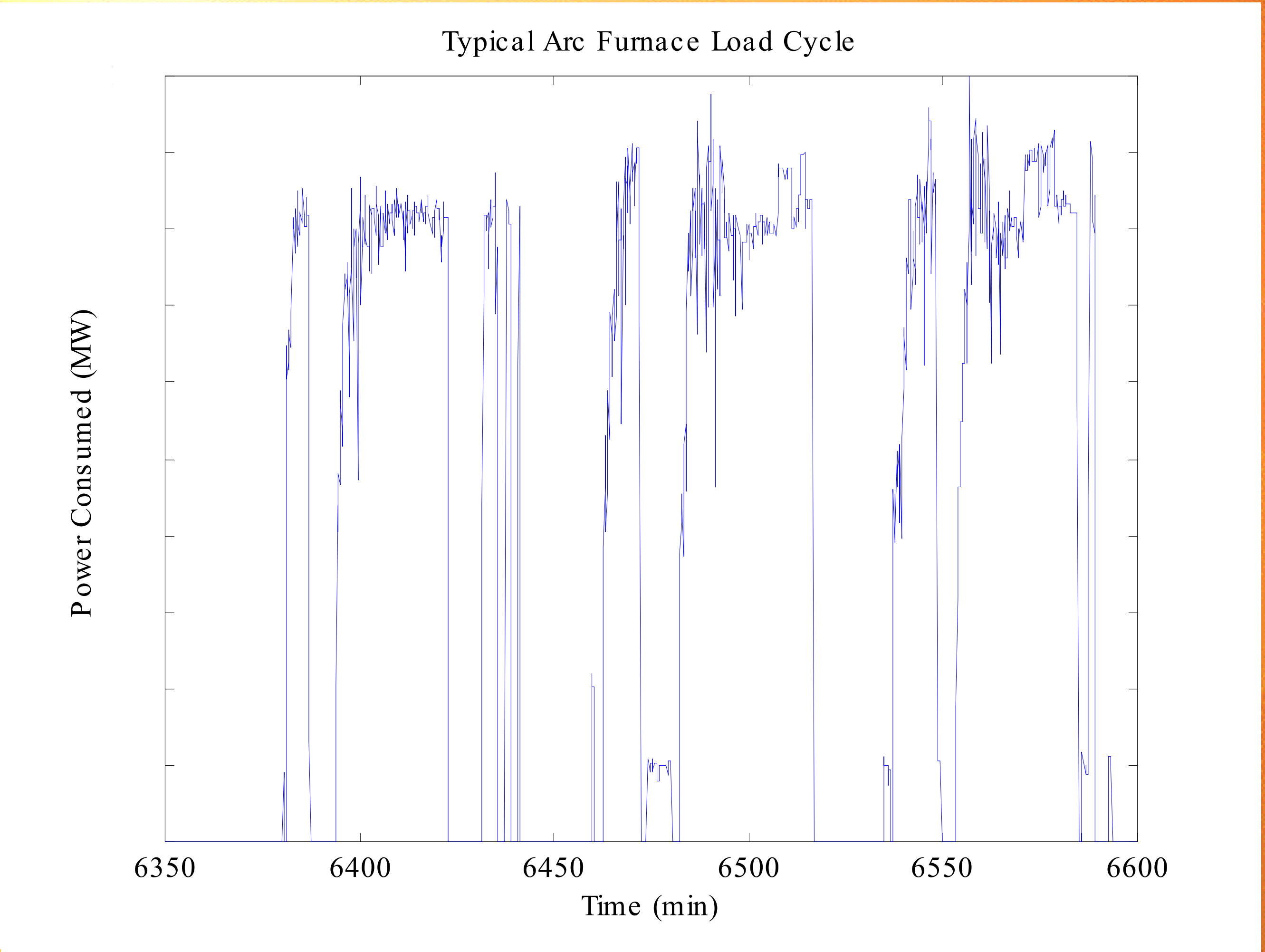
Subcontract # 45 000 13 009
Oak Ridge National Laboratory, UT- Battelle

7/26/01

Goals and Methodologies

- Goal
  - Develop a way to increase electric reliability and quality by reducing the electric fluctuations caused by large industrial loads without reducing (and hopefully increasing) productivity.
- Method
  - Develop ways to coordinate startup of large loads so that they tend to cancel out the electric transients from each other.

Large Load Swings



Overall project deliverables and impact on the industry

- Automatic Generation Control
  - Make the electric generation system perform faster and follow industrial load changes better.
- Startup Coordination
  - Use loads as part of the electric system control system.
    - Develop ways to control both arc furnaces and rolling mills.
- Control Allocation
  - Who is doing what to who.
- Economic Optimization
  - Getting the most benefit (Don't reduce productivity).
    - Reduce both energy and ancillary service costs.
    - Indirect productivity benefits and energy savings.
    - Improved electric reliability and quality.
- Regulatory Interface Concepts
  - How do we make it work in the real world?

Automatic Generation Control

- Several key characteristics of the highly varying loads would necessitate the development of advanced and intelligent control for power generation. These special HVL features include:
- 1) short time constants (high frequency)
- 2) large degree of randomness
- 3) typically unexpected start and ending times
- 4) mostly of large magnitude, requiring generation ramp up
- 5) if randomly occurring in a generation area, instability could occur
- 6) due to uncertainties involved, artificial intelligent (AI) techniques have to be incorporated into the control system
- 7) to compensate for the randomness, feedforward control with prediction capabilities must be integrated with the feedback strategies

Automatic Generation Control (cont)

Considering the uncertainties involved, a new neuro-fuzzy inference engine has been developed to handle modeling of nonlinear, uncertain characteristics of HVL's. The following figure shows the architectures of this neuro-fuzzy inference system.

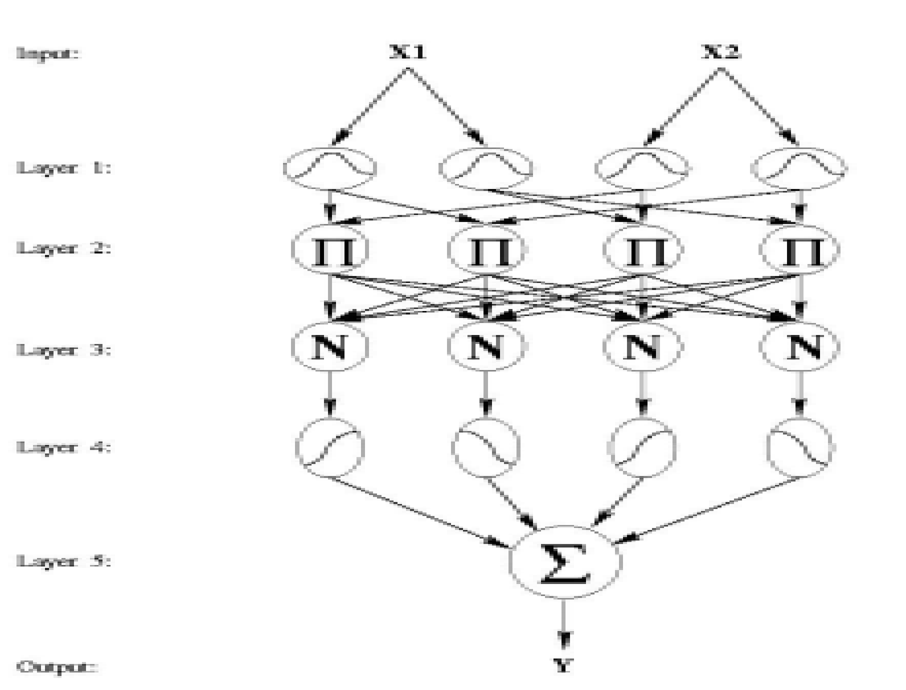


Figure 4: Neuro-Fuzzy Inference

Automatic Generation Control (cont)

- Ten inputs were introduced and varied in the testing:
  - Time
  - Generation Power
  - Generation Reactive Power
  - Area Control Error
  - Scheduled Tie Line Power
  - Tie Line Power
  - Tie Line Reactive Power
  - Frequency
  - Industrial Power
  - Industrial Reactive Power

Automatic Generation Control (cont)

- A strong correlation was found between the total load and the following inputs:
  - Time
  - Generation Reactive Power
  - Area Control Error
  - Tie Line Reactive Power
  - Industrial Power

  Industrial Reactive Power

Automatic Generation Control (cont)

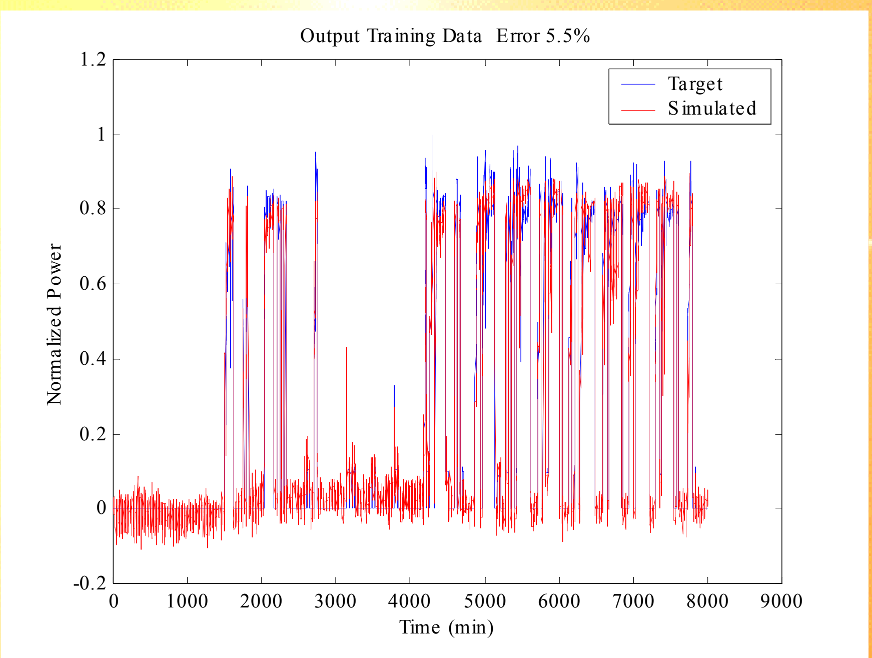


Figure 13: Training Data

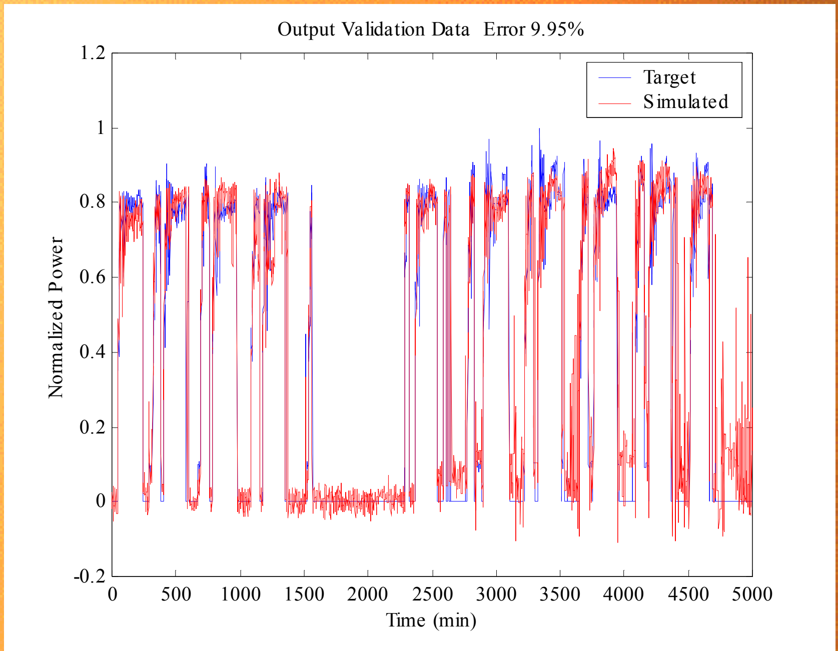
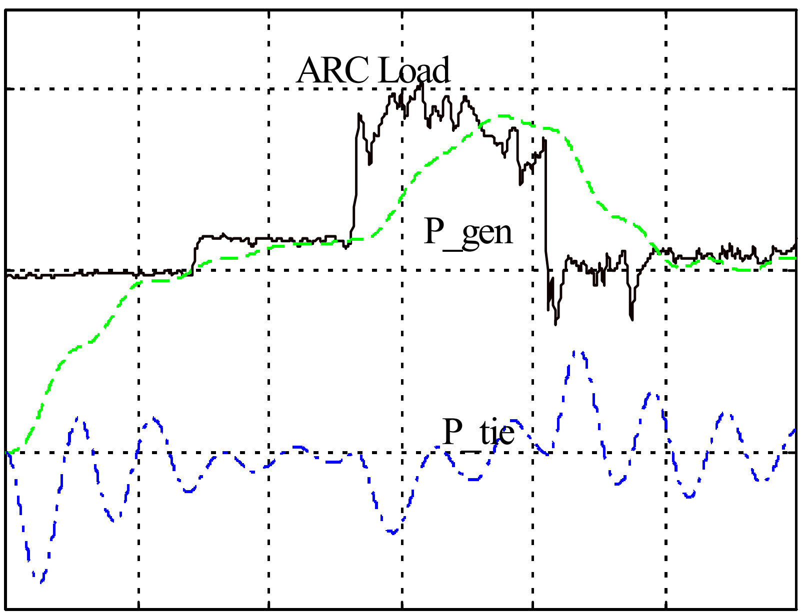


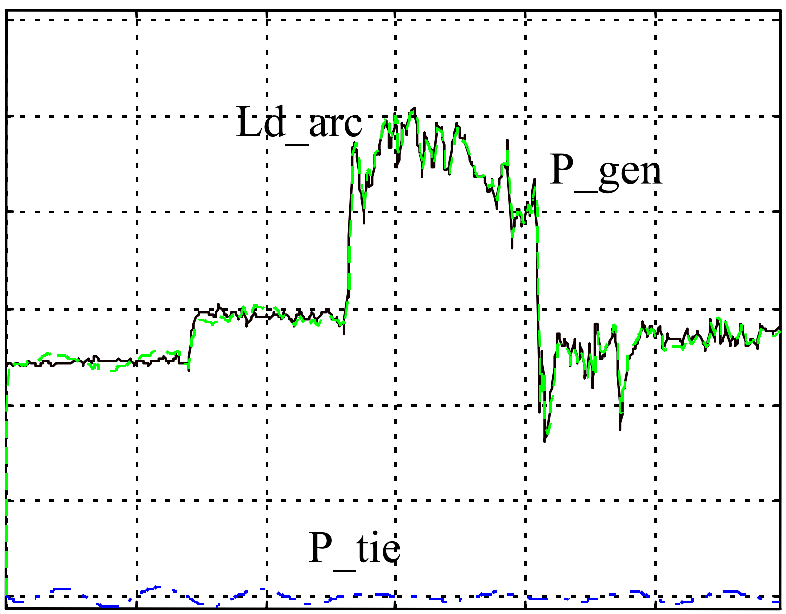
Figure 14: Validation Data

Automatic Generation Control (cont)

- Advanced AGC system developed and in test.



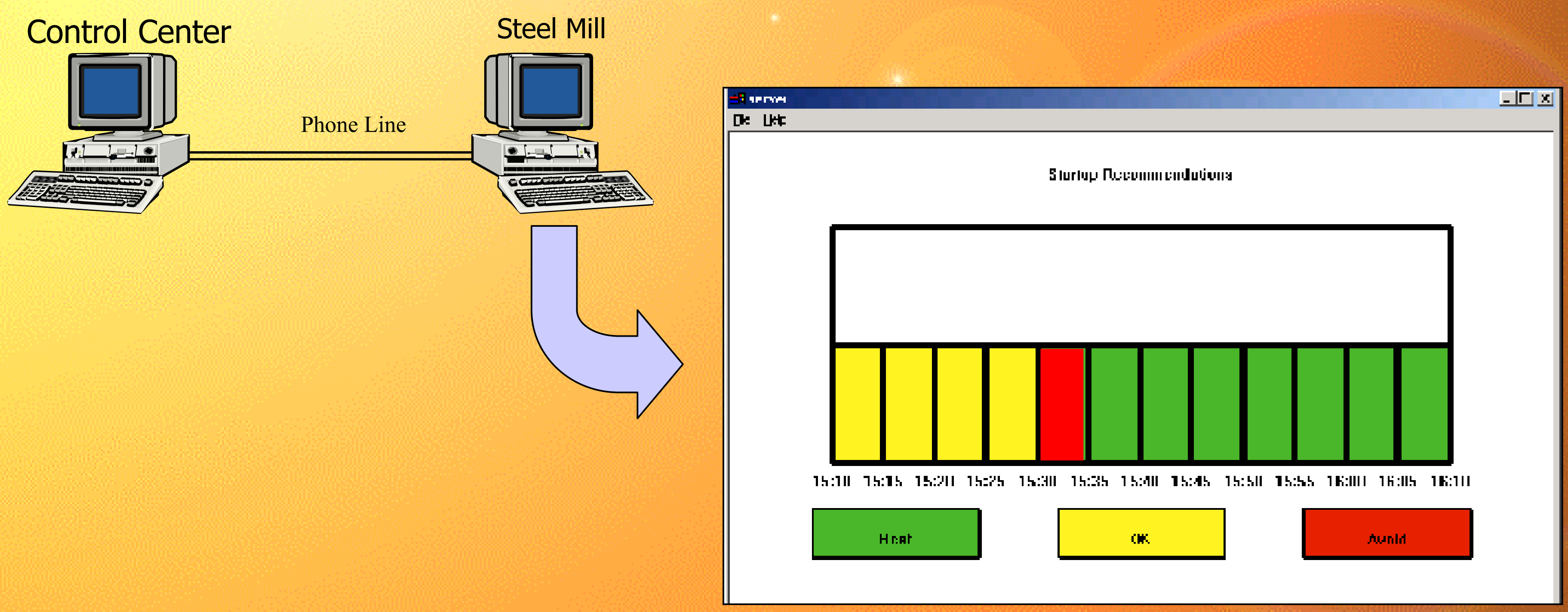
Current AGC



Intelligent AGC

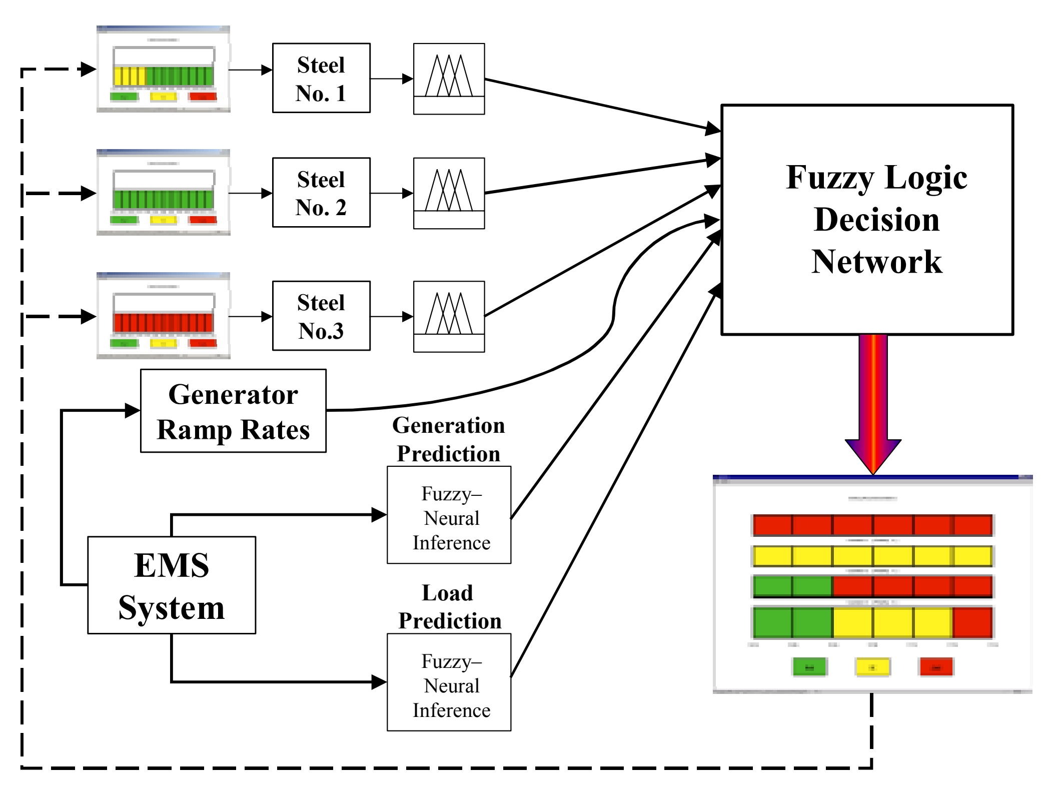
Automatic Generation Control (cont)

- Startup control system developed and in test at operating arc furnace.



Automatic Generation Control (cont)

- Startup Control for multiple arc furnaces & rolling mill in initial testing.



Control Allocation (cont)

- Initial Concerns
  - Metrics that would permit the development of models to decompose the one-minute average value of control area's ACE to zones of load buses within a control area.
  - Early efforts were based on a combination of analysis and simulations performed on a simplified mathematical model of the five-area interconnected system with the NIPSCo control area in the center.
- Currently
  - Extending results to an actual system initially using actual measurements taken from the field. Currently checking the accuracy of the model parameter estimation by comparing to field data and updating.

Control Allocation

- Method developed to separate individual control allocations.
  - Initial testing under way
  - Preliminary results promising
  - Expanding to include more regions
- ACE decomposition methodology

Step 1: Determine the values of the ACE model parameters using least square estimation.

Step 2: Use the model parameters in the state model of ACE(t) to solve for the boundary values of ACE in each minute interval.

Step 3: Compute the modeled ACE using the values of the model parameters obtained in step 1, and the boundary values of ACE obtained in step 2.

Step 4: For each defined load zone, replace the area's total load change by the corresponding sampled value of the zone's load change, and redo steps 2 and 3 to obtain the components for that zone.

Control Allocation (cont)

- Model accuracy
  - Have examined the setup of the present AGC system to understand and then to refine the model, adding the necessary functions performed by the actual AGC.
  - Issues regarding nonlinearities in various power plant components were considered.
    - Excluding random periods caused by either manual interventions or diminished plant capability, filtering and deadband with dynamic characteristics within the AGC had to be accounted for as these we found to have significant effect on the AGC loop response. Changes were made to both the model and the algorithm that performs on-line estimation of the system parameters in the ACE model.

Control Allocation (cont)

- Initial testing of a simplified model parameter estimation technique on several batches of field data started late in 2000.
  - Initial results with field data were not as good as those from earlier simulation studies.
    - The simplified model did not sufficiently account for the complex nonlinearities encountered in the actual system.
      - As changes were made to the model and the estimation techniques, the results have improved.
      - Currently, the root mean square error of the one-minute ACE between actual and that predicted by our model ranges from 10 to 35 MW for one to two hour study periods.
        - Currently identifying changes that could lead to improvement in accuracy, implementing the changes, and reverifying test results.

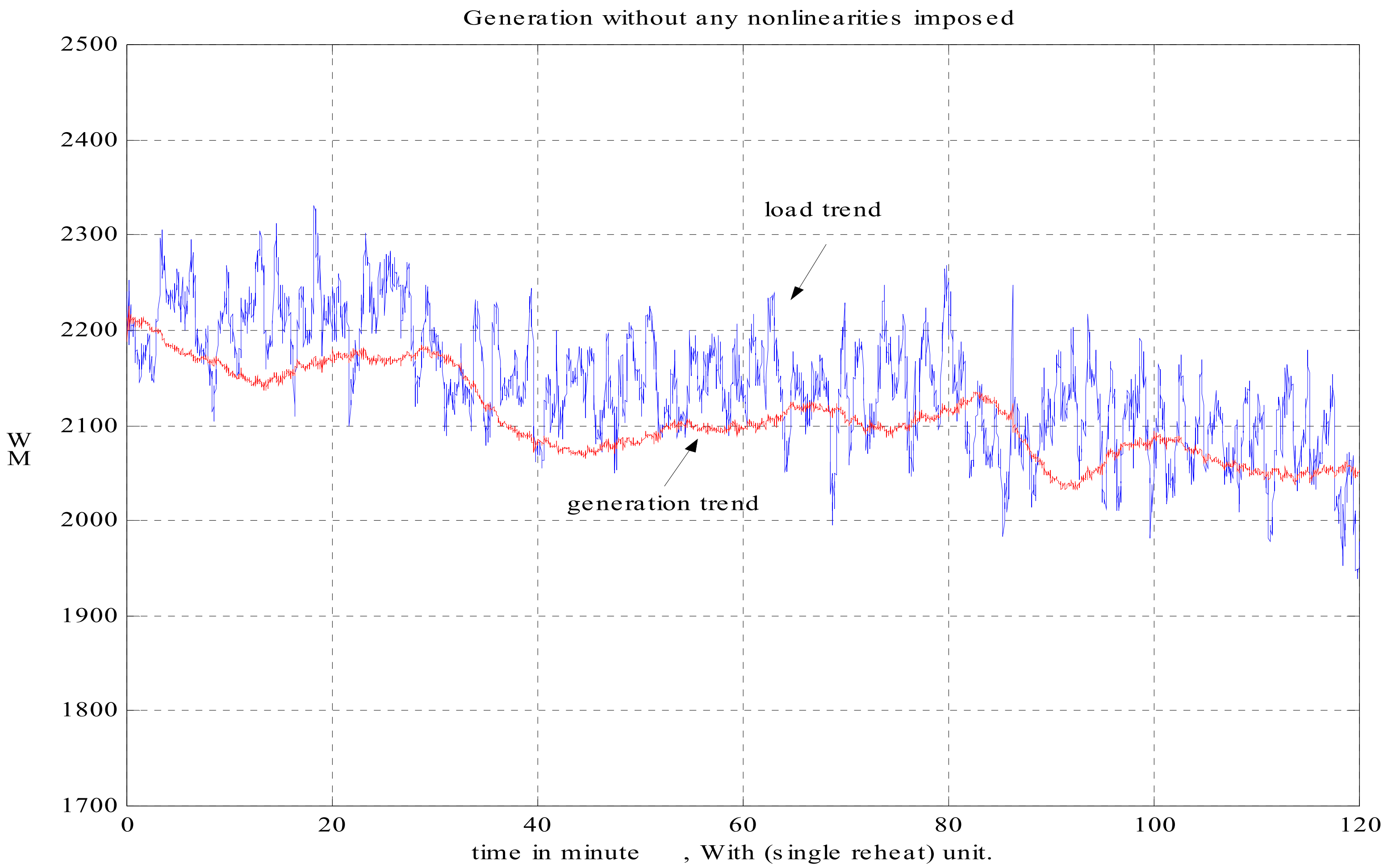
Control Allocation (cont)

Influence of Nonlinearities

- The effects of certain nonlinearities on the tracking performance of generation using simulations was considered. A ramp limit of 5-mw/min,a range limit of 320 and 350 MW, and a 35-*mHz* governor deadband was applied to the various units in the study. The generation response to an identical loading with and without the influences of these nonlinearities are shown in the following figures.
  - Comparison of the generation responses indicates that the applied nonlinearities add about 1 to 1.5 minutes of delay in generation response tracking the same loading.

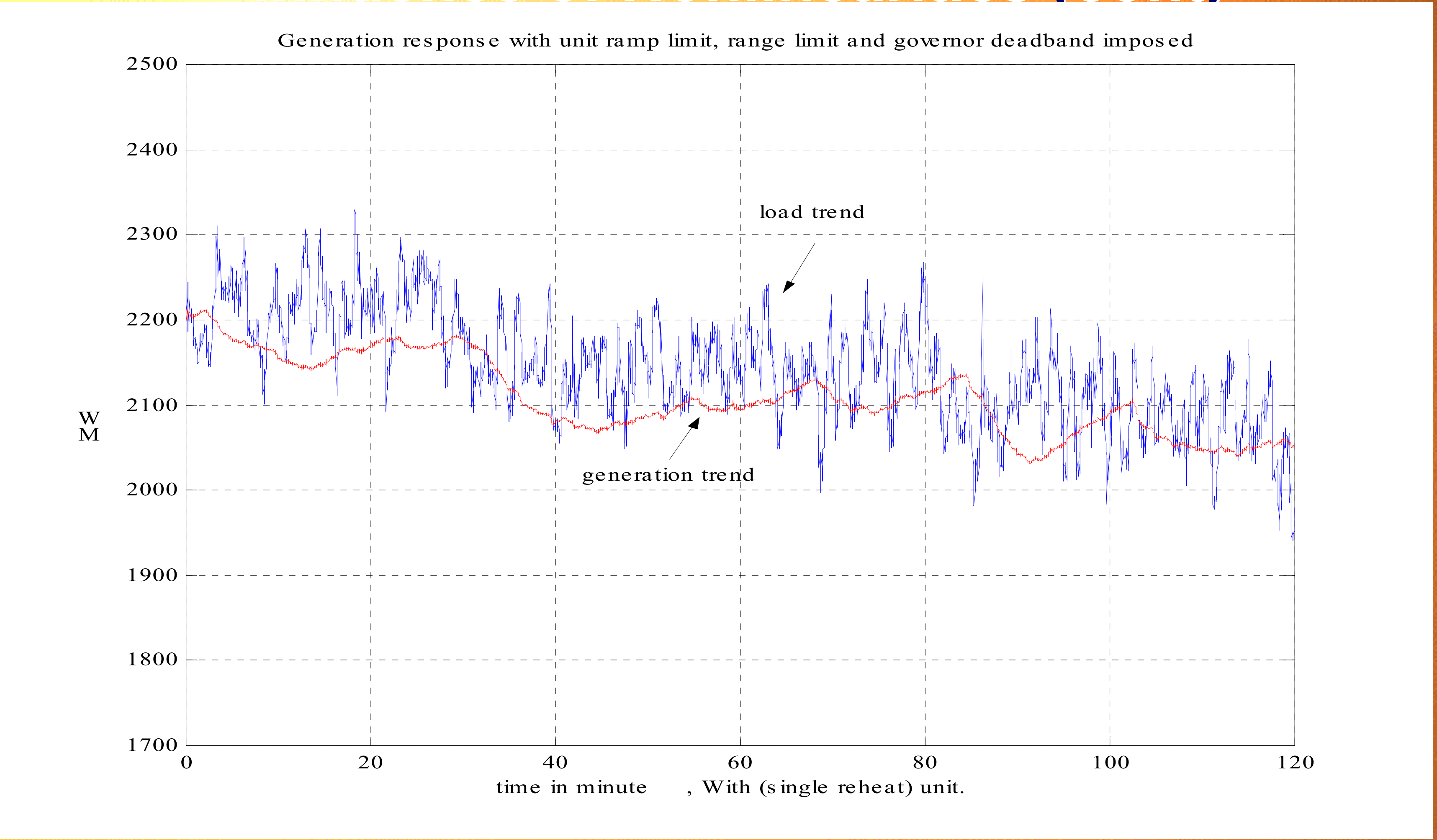
Control Allocation (cont)

Influence of Nonlinearities (cont)



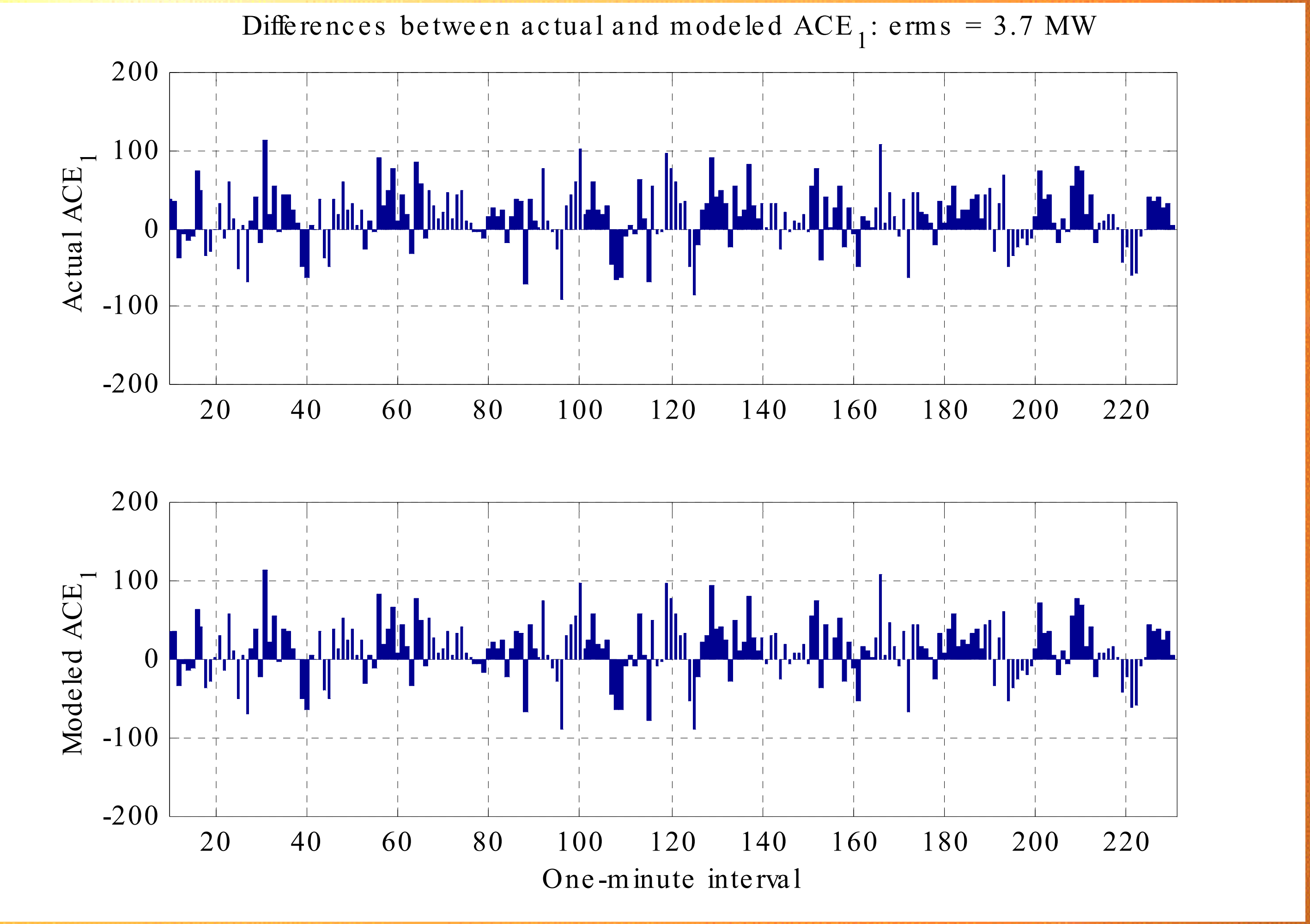
Control Allocation (cont)

Influence of Nonlinearities (cont)



Control Allocation (cont)

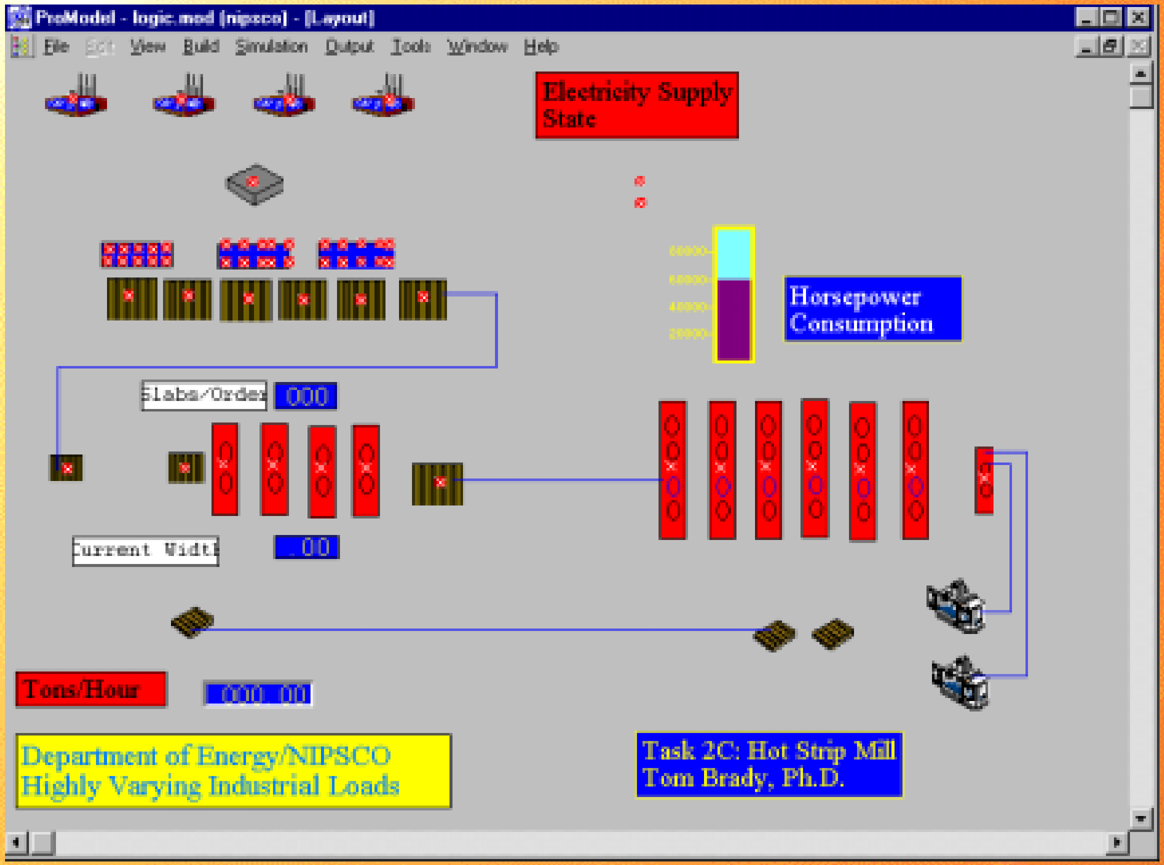
Actual vs Modeled ACE



Rolling Mill Model

- Rolling Mill Model and interface to control system in development
  - Representative of Large, Integrated Mill
    - Width Range of 30 to 84 inches
    - 3 Reheat Furnaces
    - 4 Roughing Stands
    - 6 Finishing Stands
    - Productivity Range of 400 to 900 Tons/Hour
    - 2 Coilers

Rolling Mill Model (cont)



Economic Optimization

- Economic model for allocation of ancillary services under development.
- AGC costing allocation model in testing.
- Various methods for cost optimization being developed.

Economic Optimization (cont)

- In an ideal system, generating units would be able to follow all load fluctuations perfectly, with generation matching load exactly.

- In the real world, the ideal system is unachievable due to the limitations of control systems, the slow response of generating units due to inertia, and the unpredictable nature of load variations.

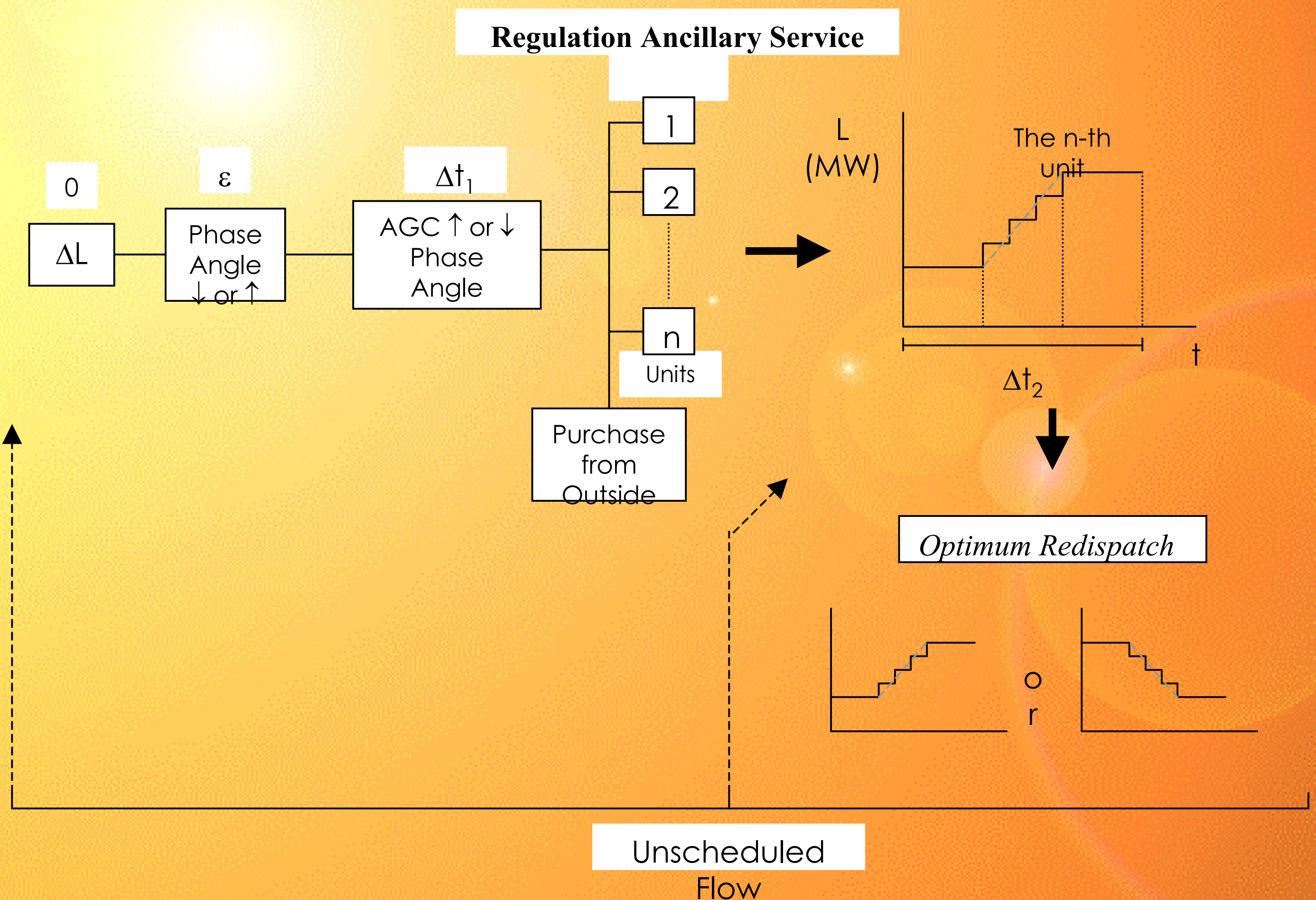
- Regulation is a practical method of reducing this problem by tracking the moment-to-moment fluctuations of customer loads, and minimizing the difference between generation output and actual load at any particular time.

- Regulation, one of the NERC-defined ancillary services, incurs cost, which should be charged to the customers that cause the load fluctuations. The costs associated with providing regulation have been categorized here into 10 types of costs:

Economic Optimization (cont)

- Wear & Tear Costs (including Fixed, and Variable Operation & Maintenance Costs)
- Cost of Departure from Optimum Heat Rate
- Cost of Departure from Optimum Dispatch Order (Ramp Limits)
- Cost of Departure from Optimum Unit Commitment
- Decreased Revenue/Increased Cost due to Transmission (Opportunity Cost)
- Environmental Costs/Benefits
- Cost of AGC System
- Cost of Anticipating Highly Varying Load (Extra Spinning Reserve to allow AGC to function)
- Penalty for Not Meeting NERC Standards (CPS1 & CPS2)

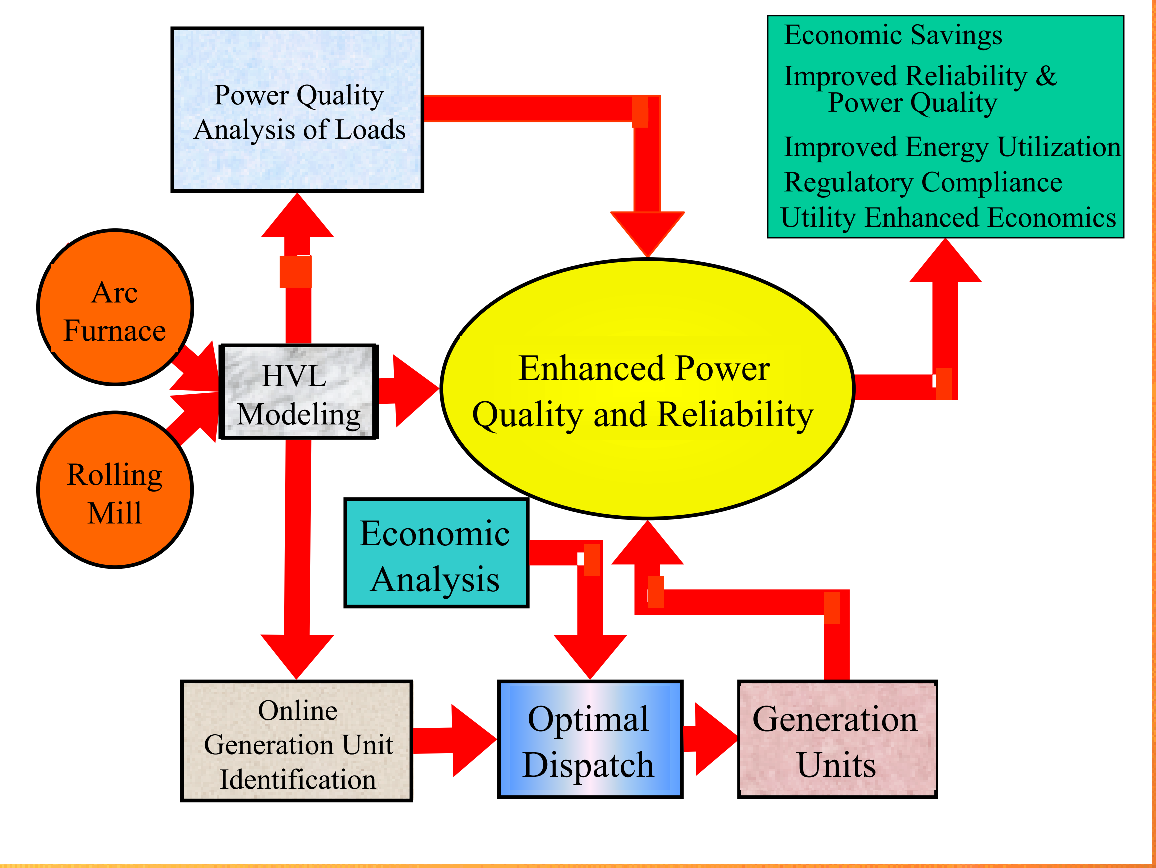
Economic Optimization (cont)



Current Efforts

- Complete models for multiple arc furnaces and rolling mill.
- Interface multiple models.
- Initiate field tests for multiple load control.
- Refine models.
- Benchmark performance.
- Interface physical models to economic and regulatory models.

Outline of Final Deliverable



Technology Transfer

- We would like to expand the participation by other steel producers (or other heavy industry with large load swings).
  - Information exchange
  - Data
  - Field Tests
  - technology
  - **A Meeting to Present Initial Results and Discuss Issues and the Future is Scheduled for 8/2/01 at NiSource in Merrillville, IN.**
    - **You are invited to attend and participate.**
      - **(219-647-5500, rakramer@nisource.com)**